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Analysis of Inclusion of Wood Forwarding into a Skidding Model

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Abstract – Nacrtak

Mechanized felling was introduced in Slovenia at the beginning of this decade, and before that Slovenian forestry relied on motor manual felling and tractor skidding or cable crane yarding. In this research we are dealing with wood forwarding. Model skidding maps were built, using terrain classification and decision support systems for forwarders and tractor trailers.

The purpose of this research is to establish how to plan in advance new individual skidding systems, which involves changing the skidding map. In the first phase, the criteria for the selection of skidding means were determined using multicriterial methodology, and then this model was applied to a study area. In the third stage we conducted a comparison between the reference map provided by the Slovenian Forest Service and the model map resulting from steps one and two. Afterwards it was determined which types of terrain were selected for forwarding and which forms of skidding would face the most serious competition from forwarding.

It was determined that the terrain allows for more forwarding than suggested by the reference skidding map. In the research area most of the forest is privately-owned, making it very unlikely that large forwarders would be used, and so tractor trailers were included in the model. Including tractor trailers we have established, that tractor skidding increases marginally at the expense of forwarding, in particular in terrain with higher terrain gradient and more difficult working conditions.

Keywords: skidding, forwarding, extraction systems, GIS, skidding map, modelling

1. Introduction – *Uvod*

Up until the beginning of this decade, when mechanized felling was introduced (Košir 2004a, Krč and Košir 2003, Košir 2004b), Slovenian forestry relied on motor manual felling and tractor skidding or cable crane skidding. Before 2000 there were only individual demonstrations of contemporary technologies. Shortwood technologies were used only in salvage cuttings of fire and storm damaged sites in the Ljubljana, Slovenj Gradec and Primorsko areas (Marušič 1998, Košir and Robek 2000, Magajna 2002). After 2000 the number of mechanized felling machines started rising, as did the number of forwarders.

Naturally, wood forwarding is about more than just forwarders, the highly-efficient machines whose price matches their features and which are used almost exclusively by larger forest management companies. Increasingly important elements of wood forwarding are also forestry trailers, which are used primarily by small forest management companies. In Slovenia it has been established (Žlogar 2007) that forwarders can use the existing skid trails for movement within the stand, while in Croatia tractor assemblies and their ecological suitability was assessed (Šušnjar et al. 2008). Ecological suitability in lowland forests was also studied on forwarder Timberjack 1710B (Horvat et al. 2004). The properties of physical working environment and technological systems are connected with different types of terrain classifications.

There are two kinds of classification systems, functional and descriptive. Functional systems classify forests in terms of potentials and limitations of technical equipment, but their use is dwindling due to the development of computers. Descriptive systems, on the other hand, are becoming increasingly useful: they classify the forest with respect to terrain characteristics that affect the use of harvesting technology. A descriptive terrain classification system must allow for a classification with varying degrees of precision and, consequently, different degrees of generalisation (Segebaden et al. 1967, Samset 1971).

There have been numerous advancements in the field of terrain classification in the recent years. There has been research into using GIS for opening forests (Tuček 1994) and terrain classification has been used for large scale harvesting operations in northern Velebit (Pentek et al. 2008). McDonagh et al. (2004) report simulating efficiency of harvesting systems using models that include terrain as one of the constraints. Digital elevation models (DEM) are being used for trafficability analysis (Kokkila 2002) and improved terrain classification parameters have been applied to harvesting on sensitive sites (Owende et al. 2002). A very important part of ecologically sound and economically feasible wood skidding in general is also the road network that has to be well planned and maintained (Potočnik 2005).

Application of DSS to terrain classification is not new. A similar method was used to plan large scale timber harvesting (Davis and Reisinger 1990). Models were developed that plan harvesting in respect to erosion and landslides (Adams et al. 2003), evaluate the feasibility of logging systems (Cavali 2006) and also predict harvesting efficiency with respect to changing stand and terrain parameters (McDoangh et al. 2004). Krč (1996) used DSS approach to predict skidding means in Slovenia, whereas in Italy a model for selecting skidding means in relation to stand and terrain parameters was built (Lubello 2008).

2. Aims – *Ciljevi*

Since almost no wood forwarding has been used in Slovenian forestry in the last 30 years, our foresters are having problems determining which areas are optimal for forwarding. This can also be seen in public forest service map, where only some terrains were selected for wood forwarding.

The purpose of this research is to establish how to plan in advance new individual skidding systems, which involves changing the skidding map and defining the types of terrain where forwarding is feasible. We also wanted to determine on which types of terrain tractor skidding will face the most serious competition from wood forwarding.

3. Material and methods – *Materijal i metode*

3.1 Study area – *Mjesto istraživanja*

The study area comprised the Bistra-Borovnica Forest Management Unit, which is located on the western edge of the Forest Management Area. The total area of the study area is 6,170 ha, of which 4,641 ha is forest.

In nearly half of the study area, 48.9%, the terrain gradient is lower than 20%, 30.1% of the area falls into the terrain gradient bracket 20–40%, 13.8% has a terrain gradient of 40–60% and the rest has a terrain gradient higher than 60%.

On the majority of the unit area (55.8%) stoniness is below 20%, it is at between 20% and 40% on 34.4% of the area, and higher than 40% on 9.8% of the area. Stoniness has been assesed as percent of the section's surface covered by visible stones. Rockiness is lower than 20% on 47.5% of the unit and 43% of the unit has rockiness of between 20% and 40%. On 9.4% of the area rockiness is above 40%. Rockiness has been evaluated similary to stoniness, and was assesed, as a percent of the section covered by rocks, or boulders, that cannot be moved.

Average skidding distance depends primarily on the road infrastructure in forests, which is expressed as road density. In the studied forestry management unit the road density is 18.6 m/ha (Šušteršič et al. 2007). In the model, however, skidding distance was calculated as the average shortest skidding distance

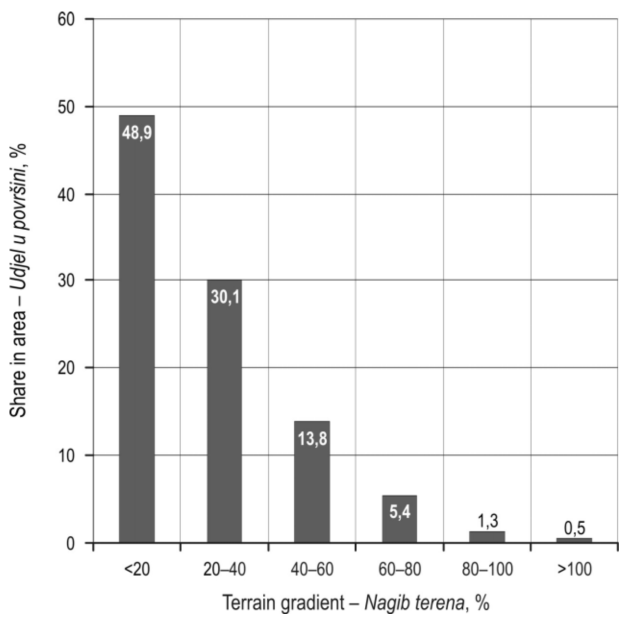

Fig. 1 Terrain gradient in the study area

Slika 1. *Nagib terena istraživanoga područja* of the forest section to the road multiplied with the factor of skidding distance, which results in model skidding distance. Skidding distance factor represents the ratio between the length of the actual skidding distance and the average shortest skidding distance (Dobre 1980). Road infrastructure in the study area is shown in Fig. 2.

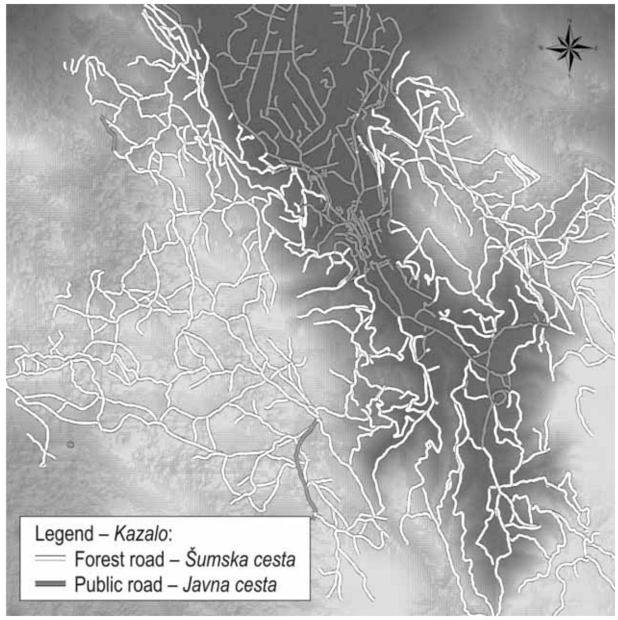

Fig. 2 Road infrastructure in the study area

Slika 2. *Cestovna mreža istraživanoga područja*

3.2 Data and model – *Podaci i model*

In the first phase, the criteria for the selection of skidding means were determined (Krč 1996) using multicriterial methodology (Saaty 1990), and then this model was applied to a study area. In the third stage, we conducted a comparison between a reference map provided by the Slovenian Forest Service and a model map resulting from steps one and two. The reference skidding map was compared to the model map. The aim of this comparison was to establish whether there were possibilities to use forwarder in parts of the study area, where the reference map does not predict forwarding. The model predicts suitability in respect to terrain classification

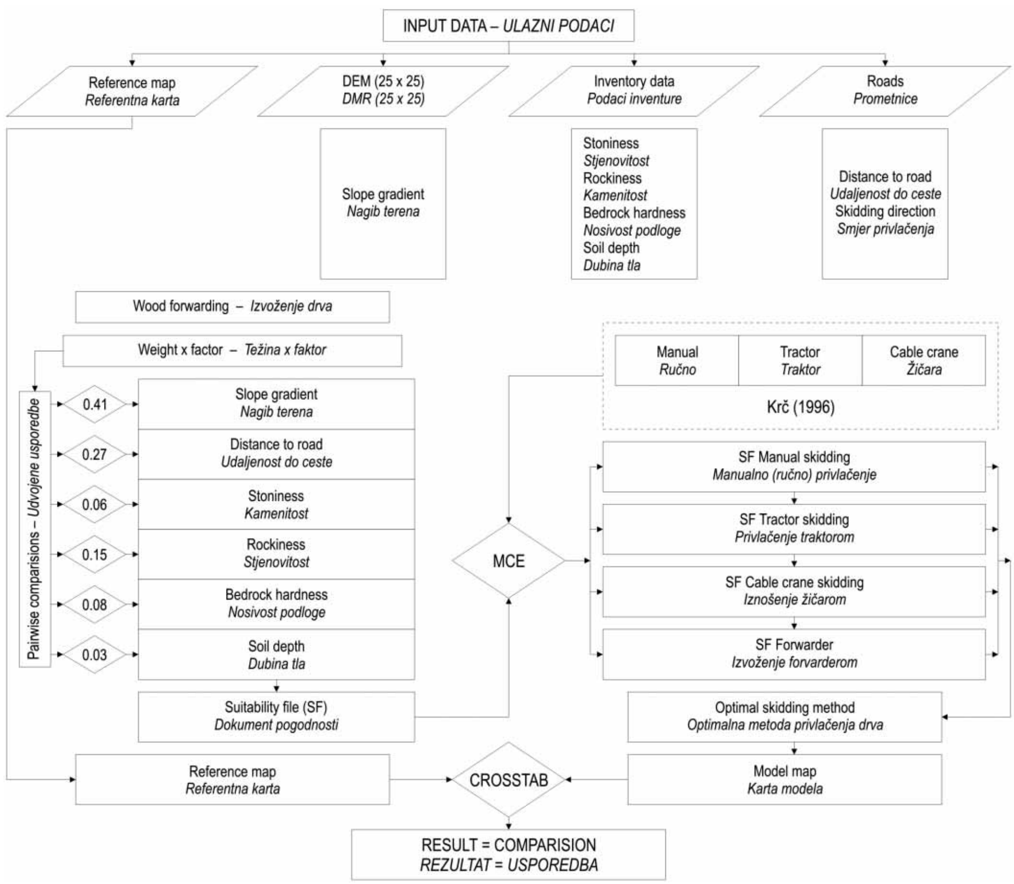

Fig. 3 Diagram of the research model

Slika 3. *Dijagram toka istraživanoga modela* for each type of skidding. A diagram of the model used is presented in Fig. 3.

Data on the terrain gradient were obtained from the digital elevation model with a resolution of 25 × 25 metres owned by the Surveying and Mapping Authority of the Republic of Slovenia; rockiness, stoniness, bedrock hardness and soil depth are data provided by the Slovenian Forest Service, and they are part of the national forest inventory; distance to forest road and skidding direction are derived from the road network and the digital elevation model (Krč and Košir 2008). Since the accuracy and reliability of the model depend primarily on the quality of input data the databases were checked for possible errors. Logical values and data completeness were also checked.

In the first phase, the skidding map was produced based on the model for predicting skidding systems. A tried-and-tested skidding model designed in the IDRISI environment was used (Krč 1996). This model uses the method of multicriteria evaluation, which is a part of decision support systems (DSS) and determines the optimal skidding technology for each cell in the raster GIS environment.

In the model, we have relied on several empirical thresholds that determine which skidding system is more suitable on terrains with certain features. In his work, Krč (1996) specifies the thresholds for manual, tractor and cable crane skidding. We have to explain, that the term »tractor skidding« refers to all types of skidders used in Slovenia, which include adapted farm tractors with winch, as well as cable skidders.

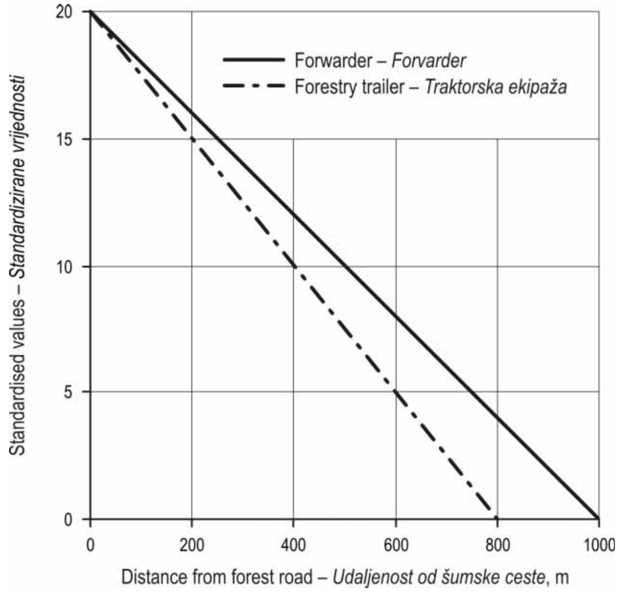

Fig. 4 Distribution of standardized value for criteria distance from forest road by determination of suitability of wood forwarding

Slika 4. *Distribucija standardiziranih vrijednosti udaljenosti od šumske prometnice s obzirom na pogodnost izvoženja drva*

The thresholds were summarized, and new ones for forwarding and forestry trailer (Fig. 3) were added using Delphi method (Okoli and Pawlowski 2004). Using this method we have determined that the maximum distance from forest road that still makes forwarding feasible was 1,000 metres, and 800 m for forestry trailer.

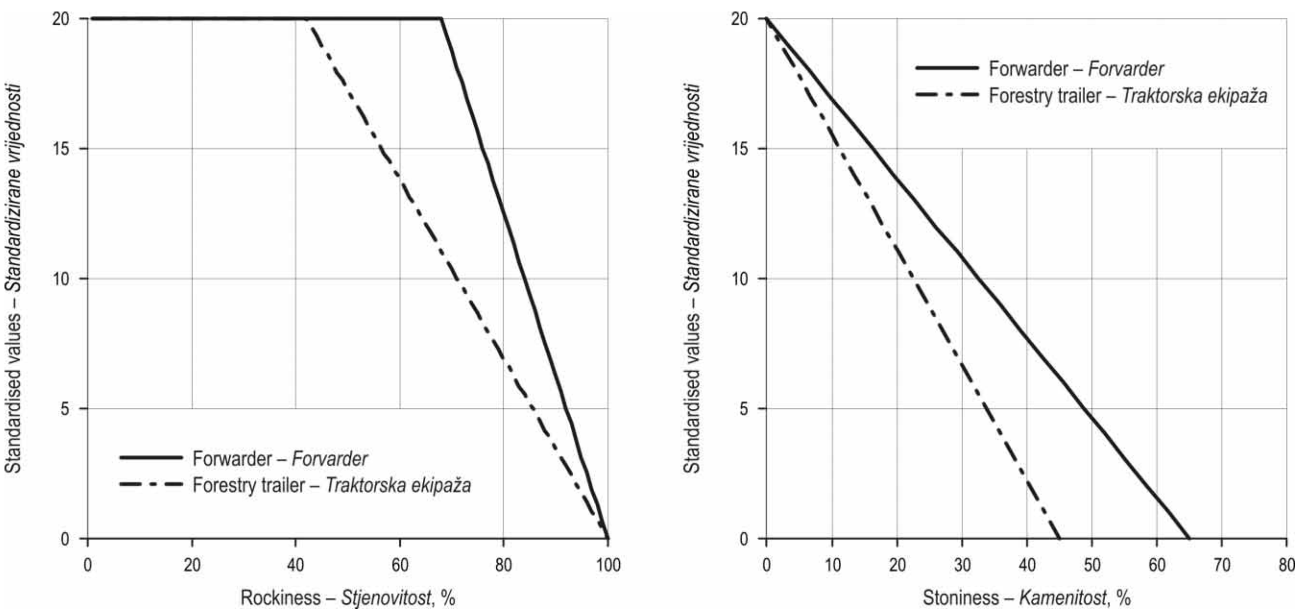

Fig. 5 Distribution of standardized value for factors of rockiness and stoniness by determination of suitability of wood forwarding

Slika 5. *Distribucija standardiziranih vrijednosti faktora stjenovitosti i kamenitosti s obzirom na pogodnost izvoženja drva*

Table 1 Assignment of standardized values to terrain gradient for the establishment of positive correlation with individual forwarding systems

Tablica 1. *Pridruživanje standardiziranih vrijednosti nagibu terena radi uspostave povezanosti s pojedinim sustavima izvoženja drva*

Extraction system	Terrain gradient – *Nagib terena*									
Sustav privlačenja drva	0–5%	5–15%	15–20%	20–30%	30–40%	40–45%	45–50%	50–60%	60–80%	>80%
Forwarder downhill *Forvarder niz nagib*	15	15	20	15	5	0	0	0	0	0
Forwarder uphill *Forvarder uz nagib*	20	15	5	0	0	0	0	0	0	0
Forestry trailer downhill *Traktorska ekipaža niz nagib*	15	20	15	5	5	0	0	0	0	0
Forestry trailer uphill *Traktorska ekipaža uz nagib*	20	5	0	0	0	0	0	0	0	0

Rockiness at 75% and stoniness at 65% were set as upper bound values still permitting forwarding, while these values were set at 40% and 45% for forestry trailer.

For soil depth it was posited that shallow soil is the best for manual skidding, tractor skidding and forwarding, and medium shallow soil less so. Deep soil is inappropriate, but it still allows for cable crane to be used. Table 1 displays thresholds for the selection of forwarding system in relation to terrain gradient, while Table 2 provides the standardized value of bedrock hardness as per individual forwarding system.

In the second step, we have applied the basic collected data, and also the data obtained in the course of research using multicriterial evaluation in our study area. Basic data used for multicriterial evaluation were rockiness, stoniness, bedrock hardness and soil depth. The processed data used as input were terrain gradient in percent, distance to forest road and skidding direction (up, down).

Following the processing, the data on individual weighing factors (Fig. 3) were merged with multicriterial evaluation into a single index that was used for comparison between skidding systems. The skidding system with the highest index value was selected.

In the third step, we have evaluated the model. This was achieved by comparing the model functional classification of the terrain with the reference map obtained from the Slovenian Forest Service. This required an alignment of the classes on the model map with those on the reference map. The model map has the following classes: manual, tractor downhill, tractor uphill, forwarder downhill, forwarder uphill, cable crane downhill and cable crane uphill. To be able to compare the maps, it was necessary to merge the classes tractor straight and tractor downhill in the Forest Service reference map, and the classes forwarder uphill and downhill on the model map, as the reference map only has the class forwarder.

In analyzing the functional classification, it should be noted that in the multicriterial evaluation weight of factors terrain gradient and skidding distance together form almost 70% of weight of all factors incorporated in the model. The analysis of the results of

Table 2 Assignment of standardized values of bedrock hardness for the establishment of positive correlation with individual skidding systems

Tablica 2. *Pridruživanje standardiziranih vrijednosti nosivosti podloge radi uspostave povezanosti s pojedinim sustavima izvoženja drva*

Extraction system	Bedrock hardness – *Čvrstoća podloge*		
Sustav privlačenja drva	Hard – *Tvrdo*	Hard/soft – *Osrednje*	Soft – *Meko*
Forwarder downhill *Forvarder niz nagib*	20	15	5
Forwarder uphill *Forvarder uz nagib*	20	15	5
Forestry trailer downhill *Traktorska ekipaža niz nagib*	20	15	5
Forestry trailer uphill *Traktorska ekipaža uz nagib*	20	15	5

functional classification will therefore focus on the terrain gradient with a weight of 41% and skidding distance, which had a weight of 27%.

The differences between the model and the reference map were compared using CROSSTAB. CROSSTAB performs a cross-tabulation analysis that compares images containing categorical variables of two types. Since the results of this module are output in the number of cells, it was also necessary to calculate cell size (0.0625 ha).

4. Results and discussions – *Rezultati i rasprava*

The comparison of the functional classifications shows that in the model classification, manual skidding is limited to extreme terrain gradients, as opposed to the reference classification, where the average terrain gradient is 48.22%. In both cases the average skidding distance is similar – 239.8 metres in the reference classification and slightly more, 257.7 metres, in the model classification. In the model classification manual skidding is assigned only to truly remote areas with a high terrain gradient. Individual classes of the reference functional classification have the following average weighing factor values.

This was followed by an analysis of the model functional classification in terms of value of weighing factors. The individual classes of the model functional classification have the following average weighing factor values.

Terrain gradients are quite high in cable crane skidding as well, averaging 47.67% for downhill skidding in the reference classification and substantially more, 68.4%, in the model classification. The distance for downhill skidding is 186.8 m in the reference classification and 380.6 m in the model classification. In cable crane skidding uphill the average terrain gradients are similar in both classifications, 51.4% in the reference and 52.4% in the model classification, whereas the skidding distance is somewhat higher in the model classification, at 180 m.

The comparison of tractor skidding shows that the model classification assumes higher average terrain gradients (43.2%) than the reference classification (28.1%). The reasons for that might lie in the fact that model classification designated a greater area for the forwarder and left only areas with the highest terrain gradient for tractor skidding. The average skidding distance is slightly longer in the model classification, at 264 m, compared to 226.3 m in the reference functional classification. In tractor skidding uphill the terrain gradient is similar (22.1% in the reference classification and 27.7% in the model classification). The model classification also determines shorter skidding distances (136.4 m) than the reference classification (176.6 m).

There is more forwarding in the model classification and at 19.1% the average terrain gradient is much lower than in the reference classification (24.9%). The model classification attributes to forwarding signifi-

Table 3 Classes of reference functional classification

Tablica 3. Razredi referentne namjenske klasifikacije terena

Extraction system *Sustav privlačenja drva*	Terrain gradient *Nagib terena*		Distance to forest road *Udaljenost do šum. ceste*		Stoniness *Sjenovitost*		Rockiness *Kamenitost*		Soil depth *Dubina tla*	
	Mean *Arit. sred.*	SE *St. pogr.*	Mean *Arit. sred.*	SE *St. pogr.*	Mean *Arit. sred.*	SE *St. pogr.*	Mean *Arit. sred.*	SE *St. pogr.*	Mean *Arit. sred.*	SE *St. pogr.*
	%		m		%		%		class – *razred*	
Manual *Ručno*	48.2	17.87	239.8	182.32	20.4	6.04	21.3	6.56	1.4	0.49
Skidder downhill *Skider niz nagib*	28.1	18.06	226.3	179.27	25.4	18.23	24.4	16.51	2.1	0.74
Skidder uphill *Skider uz nagib*	22.1	15.25	176.6	161.13	29.6	21.61	28.2	19.55	2.3	0.72
Forwarder *Forvarder*	24.9	14.27	262.8	193.89	19.7	13.21	19.8	12.69	3.0	0.53
Cable yarder downhill *Žičara niz nagib*	47.7	14.89	186.8	147.55	14.9	8.47	9.1	8.13	1.9	0.33
Cable yarder uphill *Žičara uz nagib*	51.4	14.21	154.1	98.45	17.8	3.25	17.7	6.30	1.4	0.58

Table 4 Classes of model functional classification

Tablica 4. *Razredi funkcionalne klasifikacije terena modela*

Extraction system *Sustav privlačenja drva*	Terrain gradient *Nagib terena*		Distance to forest road *Udaljenost do šum. ceste*		Stoniness *Sjenovitost*		Rockiness *Kamenitost*		Soil depth *Dubina tla*	
	Mean *Arit. sred.*	SE *St. pogr.*	Mean *Arit. sred.*	SE *St. pogr.*	Mean *Arit. sred.*	SE *St. pogr.*	Mean *Arit. sred.*	SE *St. pogr.*	Mean *Arit. sred.*	SE *St. pogr.*
	%		m		%		%		class – *razred*	
Manual *Ručno*	115.2	114.74	257.7	204.77	21.5	17.34	7.6	14.17	2.0	0.00
Skidder downhill *Skider niz nagib*	43.2	12.90	264.0	193.23	19.2	10.89	18.7	10.11	1.9	0.88
Skidder uphill *Skider uz nagib*	27.7	9.62	136.4	138.22	19.4	12.31	18.9	11.76	2.3	0.75
Forwarder *Forvarder*	19.1	10.16	206.8	162.61	28.4	20.75	27.4	18.83	2.4	0.65
Cable yarder downhill *Žičara niz nagib*	68.4	11.51	380.6	235.45	22.8	10.21	22.2	10.30	1.2	0.63
Cable yarder uphill *Žičara uz nagib*	52.4	12.45	180.0	153.22	18.6	7.40	18.3	9.28	10.6	0.79

cantly shorter average skidding distances (206.8 m) than the reference classification (262.8 m).

Fig. 6 shows the reference skidding map made by the Forest Service (left) and the model of skidding systems for the study area (right). The image shows a skidding model complemented with forwarding.

We have compared the two maps using Idrisi module Crosstab. The results of the comparison are presented in Tables 5 and 6.

The model was designed to establish which skidding system would be best for the given terrain. It was established that forwarding appears in areas

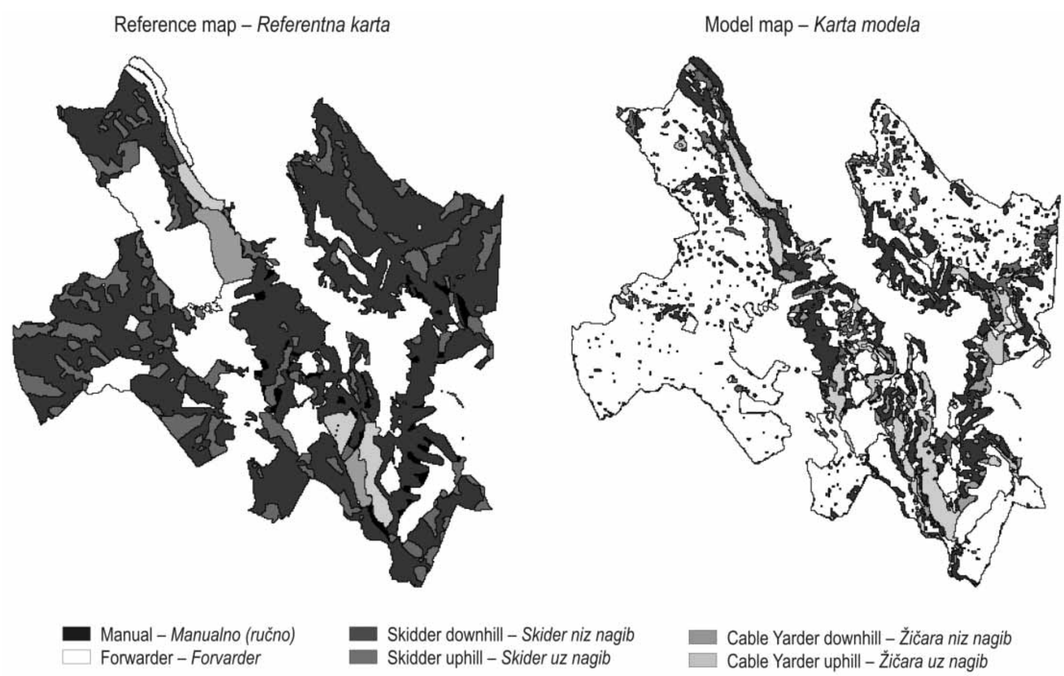

Fig. 6 Reference map of skidding systems (Forest Service) and model for skidding with forwarder

Slika 6. *Referentna karta sustava privlačenja drva (Javna šumarska služba) i karta modela za izvoženje drva forvarderom*

Table 5 Overlap between the model map and the reference map for the use of forwarder*

Tablica 5. *Preklapanje između karte modela i referentne karte za uporabu forvardera**

Reference map – *Referentna karta*	Model map – *Karta modela*: Manual *Ručno*	Skidder downhill *Skider niz nagib*	Skidder uphill *Skider uz nagib*	Forwarder *Forvarder*	Yarder downhill *Žičara niz nagib*	Yarder uphill *Žičara uz nagib*	Total *Ukupno*
Manual *Ručno*	0.0	0.9	0.1	0.1	0.0	0.0	1.13
Skidder downhill *Skider niz nagib*	27.3	551.1	51.5	81.3	51.0	9.4	771.56
Skidder uphill *Skider uz nagib*	3.1	138.4	71.1	28.0	5.6	7.1	253.25
Forwarder *Forvarder*	12.1	1682.9	554.4	313.3	21.1	12.7	2596.50
Yarder downhill *Žičara niz nagib*	9.2	90.6	4.6	5.4	14.8	4.9	129.50
Yarder uphill *Žičara uz nagib*	8.9	137.0	61.3	10.7	32.4	95.6	345.81
Total *Ukupno*	60.56	2600.88	742.94	438.81	124.88	129.69	4097.75

* the quantities are in hectares – *vrijednosti izražene u hektarima*

with a lower average terrain gradient than tractor skidding, which is shown in Fig. 7. Average skidding distances are shorter than those assigned to forwarding in the reference classification.

The reference skidding map shows the current use of skidding systems, which depend on a number of factors. Most of the factors had not been included in the model, for example forest ownership structure, growing stock, proximity of off-limits areas (military installations), existing infrastructure and microrelief features. These factors have not been included in the model because the relations between the factors and their suitability for different skidding systems have not been determined yet. Including these factors into the model is to be the subject of future research. Differences between the models do af-

Table 6 Overlap between the model map and the reference map for the use of forwarder*

Tablica 6. *Preklapanje između karte modela i referentne karte za uporabu forvardera**

Reference map – *Referentna karta*	Model map – *Karta modela*: Manual *Ručno*	Skidder downhill *Skider niz nagib*	Skidder uphill *Skider uz nagib*	Forwarder *Forvarder*	Yarder downhill *Žičara niz nagib*	Yarder uphill *Žičara uz nagib*
Manual *Ručno*	0.0	81.8	9.1	9.1	0.0	0.0
Skidder downhill *Skider niz nagib*	3.5	71.4	6.7	10.5	6.6	1.2
Skidder uphill *Skider uz nagib*	1.2	54.6	28.1	11.1	2.2	2.8
Forwarder *Forvarder*	0.5	64.8	21.4	12.1	0.8	0.5
Yarder downhill *Žičara niz nagib*	7.1	70.0	3.6	4.2	11.4	3.8
Yarder uphill *Žičara uz nagib*	2.6	39.6	17.7	3.1	9.4	27.6

* the quantities are in percents – *vrijednosti izražene u postotcima*

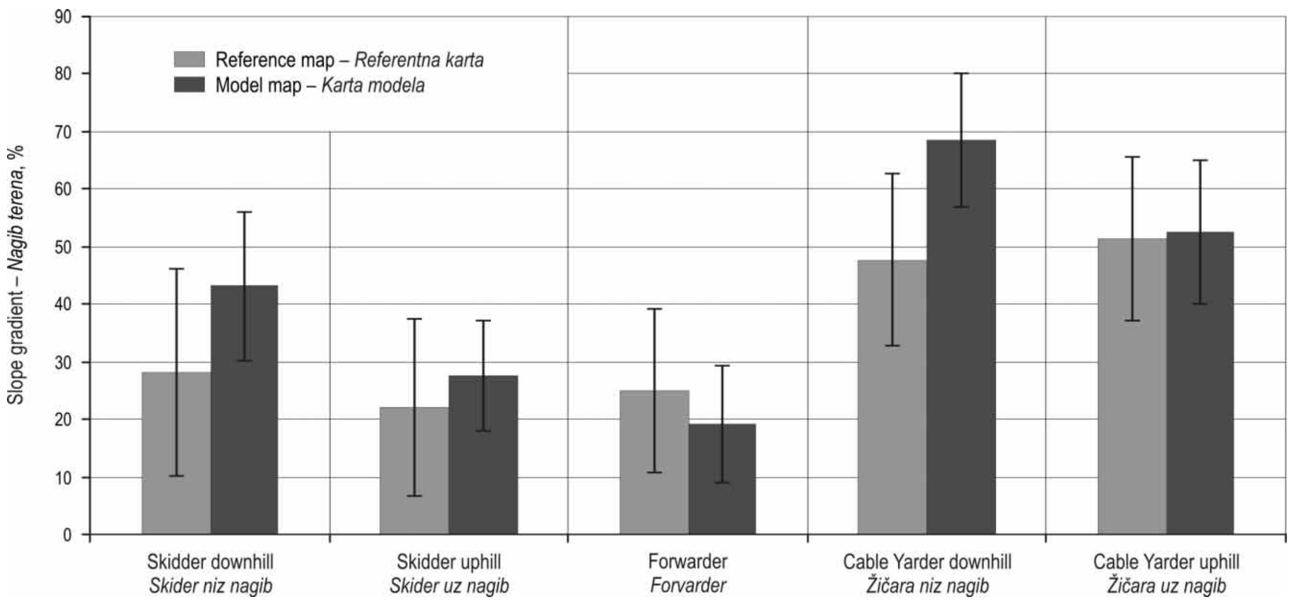

Fig. 7 Terrain gradient for individual skidding systems in reference and model classifications

Slika 7. *Nagibi terena za primjenu pojedinih sustava privlačenja drva u referentnoj karti i karti modela*

fect the results of the comparison analysis. The purpose of the constructed model, however, was to consider the possibility of wood forwarding in regard to terrain conditions, which is why the comparison analysis can be conducted.

The results of the skidding model with respect to the terrain have shown that the model designates substantially larger areas to forwarding than the reference skidding map. However, it is also true that the reference skidding map considers skidding in combination with mechanized felling and, consequently, with specific stand, ownership, environmental and technical-organisational circumstances.

The conclusion for manual skidding is that the model and the reference map do not overlap. The fact is that the most important weighing factor in the model is the terrain gradient; there are few extreme slopes in the Bistra-Borovnica Forest Management Unit, which is why the model determined much fewer areas suitable for manual skidding than the reference map. On the reference map meanwhile, manual skidding is conditional on several factors, primarily microrelief features, which cannot be determined with a digital elevation model with a resolution of 25 × 25 metres.

The analysis of tractor skidding uphill and downhill is particularly interesting, as tractor skidding is present on the majority of areas of the reference map, whereas the model shows that much more of the area is suitable for forwarding: in the model forwarding took up 64.7% of the area previously deemed suitable for tractor skidding downhill, and 21.4% of the area previously assigned to tractor skidding uphill.

The terrain which was classified as tractor skidding in both classifications was additionally analyzed. In tractor skidding downhill it was established that the terrain was relatively flat, with 80% of

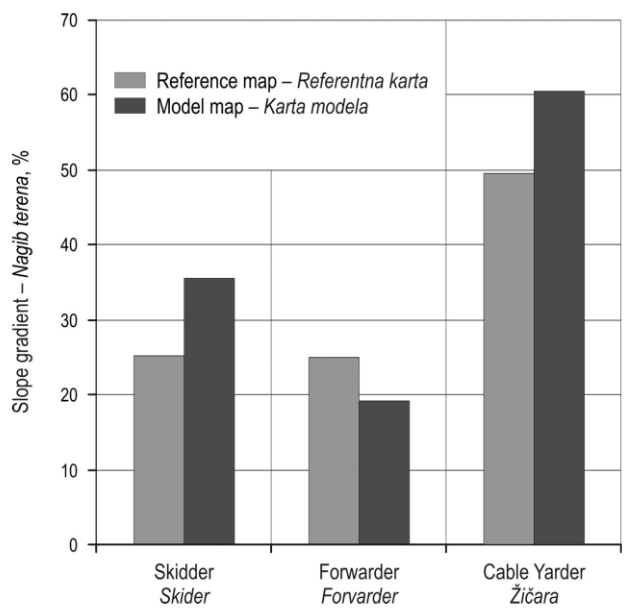

Fig. 8 Skidding by system in the reference and model classifications depending on average terrain gradient

Slika 8. *Sustavi privlačenja drva pri referentnoj i oblikovanoj razredbi ovisno o prosječnom nagibu terena*

Table 7 Overlap between the model map and the reference map for the use of tractor trailer*

Tablica 7. *Preklapanje između karte modela i referentne karte za uporabu traktorskih ekipaža**

		Model map– *Karta modela*					
		Manual *Ručno*	Skidder downhill *Skider niz nagib*	Skidder uphill *Skider uz nagib*	Forwarder *Forvarder*	Yarder downhill *Žičara niz nagib*	Yarder uphill *Žičara uz nagib*
Reference map – *Referentna karta*	Manual *Ručno*	0.0	0.3	0.2	0.0	0.0	0.0
	Skidder downhill *Skider niz nagib*	17.4	379.5	45.3	62.7	41.7	7.0
	Skidder uphill *Skider uz nagib*	5.1	450.8	318.6	90.9	8.3	10.0
	Forestry trailer *Traktorska ekipaža*	8.6	1354.4	295.7	258.2	18.9	7.6
	Yarder downhill *Žičara niz nagib*	18.2	251.9	15.4	13.0	22.9	7.3
	Yarder uphill *Žičara uz nagib*	9.4	153.1	65.5	11.7	32.9	97.3

* the quantities are in hectares – *vrijednosti izražene u hektarima*

the area falling into the terrain gradient bracket 15–30%. The 15–20% and the 25–30% brackets took up 20% of the area each and the 20–25% bracket 40% of the area. Distance to forest road is below 300 m on 70% of the area; extending the distance to 500 m captures as much as 84% of the area. Stoniness is relatively low, as 73% of the area has a stoniness of between 0% and 20% and another 15% of the area falls into the 20–30% bracket. Rockiness is similar: the 0–20% bracket covers 72% of the area and the 20–30% bracket another 20%. Most downhill skidding (84.5%) is carried out on hard bedrock and 88% on very shallow or shallow soil.

The terrain that produced the selection of tractor skidding uphill in both classifications has a terrain gradient of 20–25% on 42.8% of the area and a more moderate 15–20% on 36.3% of the area. 15% of the skidding is done on terrain gradients lower than 15%. Skidding distances are shorter than in downhill skidding, remaining below 100 metres on as much as

Table 8 Overlap between the model map and the reference map for the use of tractor trailer*

Tablica 8. *Preklapanje između karte modela i referentne karte za uporabu traktorskih ekipaža**

		Model map – *Karta modela*					
		Manual *Ručno*	Skidder downhill *Skider niz nagib*	Skidder uphill *Skider uz nagib*	Forwarder *Forvarder*	Yarder downhill *Žičara niz nagib*	Yarder uphill *Žičara uz nagib*
Reference map – *Referentna karta*	Manual *Ručno*	0.0	70.0	30.0	0.0	0.0	0.0
	Skidder downhill *Skider niz nagib*	3.1	68.5	8.2	10.2	7.5	1.3
	Skidder uphill *Skider uz nagib*	0.6	51.0	36.0	10.3	0.9	1.1
	Forestry trailer *Traktorska ekipaža*	0.5	69.7	15.2	13.3	1.0	0.4
	Yarder downhill *Žičara niz nagib*	5.5	76.6	4.7	4.0	7.0	2.3
	Yarder uphill *Žičara uz nagib*	2.5	41.4	17.7	3.2	8.9	26.3

* the quantities are in percents – *vrijednosti izražene u postotcima*

61% of the area; only 15.0% of the skidding is done on distances longer than 200 m. The entire area has hard ground and most of the skidding is done on shallow (37.6%) and medium soil (43.5%). On over 70% of the area rockiness and stoniness are below 20%.

In cable crane skidding the overlap between the model and the reference map is relatively small, 73.7% for uphill cable crane skidding and only 11.9% for downhill cable crane skidding. In the model classification a large part of both types of cable crane skidding is taken over by tractor skidding: 40.8% of downhill cable crane skidding and 7.3% of uphill use of the cable crane. There are several reasons, including the relative openness of the unit, small share of deep soil on which the cable crane is the only option, and the relative flatness of the unit, which further reduces the area appropriate for the cable crane.

Fig. 8 merges uphill and downhill skidding, showing only skidding by system in order to make more clear the terrain gradient at which forwarding takes over in the reference model, and the fact that in the descriptive classification tractor skidding is present only in terrain that has higher terrain gradients than terrain suitable for forwarding.

It was also interesting how the model map changed if forestry trailer was used instead of forwarder. The parameters were changed, and the model – this time for the forestry trailer – compared to the reference map.

The results, in Tables 7 and 8 show a small increase of surface assigned to tractor skidding and a minor decrease of surfaces assigned to forestry trailer, while values for cable crane skidding remain at the same level.

5. Conclusion – *Zaključci*

It was determined that the terrain allows for more forwarding than suggested by the reference skidding map. The biggest change was observed in tractor skidding: in the model forwarding it took up to 64.7% of the area previously designated for tractor skidding downhill and 21.4% of the area previously designated for tractor skidding uphill. A more detailed analysis has led to the conclusion that the optimal terrain for tractor skidding downhill is on terrain gradient of below 30% and over a skidding distance of up to 300 m (a distance of up to 500 m is still acceptable). Stoniness and rockiness should be low, at less than 20%, the ground should be hard and the soil shallow. Tractor skidding uphill would be best at terrain gradients of up to 25% and at shorter skidding distances, below 200 m. The ground should be hard, with rockiness and stoniness not exceeding 20%.

A comparison of cable crane skidding and forwarding shows that the model classification assumes higher average terrain gradients for cable crane skidding (43.19%) than the reference classification, where the average terrain gradient is 28.14%. The reasons may lie in the fact that the model classification designated more areas to skidding with forwarder, leaving only areas with higher terrain gradient for cable crane skidding. The average skidding distance is higher in the model classification (264.03 m) than in the functional classification (226.26 m). The terrain gradient for cable crane skidding uphill is comparable, averaging 22.09% in the reference classification and 27.67% in the model classification. At 136.55 m, the model classification determines shorter skidding distances than the reference classification (176.71 m).

In our study area most of the forest is privately-owned, making it very unlikely for large forwarders to be used. The fact is that cooperation between forest owners is very poorly developed in Slovenia, which means that the felling and skidding will be done by small contractors for whom a forestry trailer is a more accessible and economical option than a forwarder. This is the reason why forestry trailer was included in the model. The results show that there is a marginal increase of tractor skidding and a decrease of surface assigned to forestry trailer. Terrains reassigned from forestry trailer to tractor skidding have higher terrain gradients and more difficult working conditions.

The model described is very dependent on input data and the suitability criteria, which define individual skidding systems. With future improvements of digital elevation models, the use of LIDAR and inclusion of suitability criteria for other factors into the model we expect higher accuracy of the model results. It would be interesting to compare the results of this model with the model using DEM with a higher resolution. Inclusion of ecological constraints, for instance Natura 2000, and functions of the forests remain challenges for the future.

6. References – *Literatura*

Adams, J. D., Visser, R. J. M., Prisley, S. P., 2003: Modeling Steep Terrain Harvesting Risks Using GIS. Precision forestry, Proceedings of the second international precision forestry symposium, Seattle, Washington, June 15–17, 2003: 99–108.

Davis, C. J., Reisinger, T. W., 1990: Evaluating Terrain for Harvesting Equipment Selection. International journal of forest engineering 2(1): 9–16.

Cavalli, R., Grigolato, S., Lubello, D., 2006: Planning logging systems through site analysis. IUFRO Precision Forestry Conference 2006, Precision Forestry in plantations, semi-natural and natural forests, March 5–10, 2006, Stellenbosch University: 319–330.

Dobre, A., 1980: Odprtost gozdov v Sloveniji. Inštitut za gozdno in lesno gospodarstvo, Ljubljana, 142 p.

Horvat, D., Poršinsky, T., Krpan, A., Pentek, T., Šušnjar, M., 2004: Suitability evaluation of forwarders based on morphological analysis. Strojarstvo 46 (4–6): 149–160.

Kokkila, M., 2002: Digital elevation models (DEM) in trafficability analysis. ECOWOOD studies. University of Helsinki, 17 p.

Košir, B., Robek, R., 2000: Characteristics of the stand and soil damage in cut-to-length thinning on the Žekanc working site (SW Slovenia). Zb. gozd. lesar. 62: 87–115.

Košir, B., 2004a: Work efficiency in mechanized cutting. Gozd. vestn. 62(1): 19–24.

Košir, B., 2004b: Operational planning in mechanized cutting. Gozd. vestn. 62 (1): 25–31.

Krč, J., Košir, B., 2003: The suitability evaluation of cut--to-length in Slovenia in view of terrain and stand. Zb. gozd. lesar. 71: 5–18.

Krč, J., 1996: A model of timber skidding predicting. Proceedings »Planning and implementing forest operations to achieve sustainable forests« 19th Annual Meeting of COFE& IUFRO SGS3.04–00, July 29–August 1, 1996, Marquette, Michigan USA: 277–282.

Krč, J., Košir, B., 2009: Predicting Wood Skidding Direction on Steep Terrain by DEM and Forest Road Network Extension. Croat. j. for. eng. 29 (1): 1–12.

Lubello, D., 2008: A rule-based SDSS for integrated forest harvesting planning. University of Padova, Dissertation: 213 p.

Magajna, 2002: Nekatere predhodne gozdnogojitvene usmeritve pri uvajanju strojne sečnje v Sloveniji. Strojna sečnja v Sloveniji, Ljubljana, Gospodarska zbornica Slovenije, Združenje za gozdarstvo: 33–47.

Marušič, J., 1998: Cutting time study of Timberjack harvester FMG 1270 in Forest Management Unit Ravnik. Graduation thesis, Ljubljana: 38 p.

McDonagh, K. D., Meller, R. D., Visser, R. J. M., McDonald, T. P., 2004: Harvesting System Simulation Using a Systems Dynamic Model. Southern Journal of Applied Forestry 28(2): 91–99.

Okoli, C., Pawlowski, S. D., 2004: The Delphi method as a research tool: an example, design considerations and applications. Information & Management 42: 15–29.

Owende, P. M. O., Lyons, J., Haarla, A. R., Peltola, A., Spinelli, R., Molano, J., Ward, S. M., 2002: Operations protocol for Eco-efficient Wood Harvesting on Sensitive Sites. Project ECOWOOD, Funded under the EU 5th Framework Project: 1–74.

Pentek, T., Poršinsky, T., Šušnjar, M., Stankić, I., Nevečerel, H., Šporčić, M., 2008: Environmentally Sound Harvesting Technologies in Commercial Forests in the Area of Northern Velebit – Functional Terrain Classification. Period. biol. 110(2): 127–135.

Potočnik, I., Yoshioka, T., Miyamoto, Y., Igarashi, H., Sakai H., 2005: Maintenance of forest road network by natural forest management in Tokyo University Forest in Hokkaido. Croat. j. for. eng. 26(2): 71–78.

Saaty, T. L., 1990: How to make a decision: The Analytic Hierarchy Process. European Journal of Operational Research 48: 9–26.

Samset, I., 1971: Classification of terrain and operational systems. Joint FAO/ECE/ILO Committee on Forest Working Techniques and Training of Forest Workers, Symposium on forest operations in mountainous regions, 30 aug. – 11 sept. 1971, Krasnodar: 22 p.

Segebaden, G. von, Stromnes, R., Winer, H. I., 1967: Proposal for an international system of terrain classification. Proceedings of the XIV IUFRO world congress, III (31–32).

Šušnjar, M., Horvat, D., Kristić, A., Pandur, Z., 2008: Morphological analysis of forest tractor assemblies. Croat. j. for. eng. 29(1): 41–51.

Šušteršič, B., Jeklar, A., Matjašič, D., Jurjevčič, B., 2007: Forest management plan of the Bistra – Borovnica management unit 2006–2015. Zavod za gozdove Slovenije, Območna enota Ljubljana, Ljubljana: 175 p.

Tuček, J., 1994: Using the GIS environment for opening-up forests. Proceedings of the international IUFRO, FAO, FEI seminar on forest operations under mountainous conditions, Harbin, China: 58–65.

Žlogar, J., 2007: Suitability of tractor skid roads for forwarding. Graduation thesis, Ljubljana: 57p.

Sažetak

Analiza uključivanja izvoženja drva forvarderom i traktorskom ekipažom u model privlačenja drva

Strojna se sječa u Sloveniji počela primjenjivati početkom ovoga desetljeća. Prije toga slovensko se šumarstvo oslanjalo na ručno-strojnu sječu i privlačenje traktorima ili šumskim žičarama. Ovo se istraživanje odnosi na *proučavanje izvoženja drva forvarderima. Oblikovane su karte načina privlačenja uz primjenu razredbe terena i sustava podrške odlučivanju za forvardere i traktorske ekipaže. Namjena je ovoga istraživanja uspostava i donošenje planova za pojedine sustave pridobivanja drva, što uključuje izmjene postojećih karata načina primarnoga transporta drva uz determinaciju onih terena koji su pogodni za rad forvardera.*

Istraživanje je obavljeno u gospodarskoj jedinici Bistra-Borovnica koja je smještena u zapadnom dijelu slovenskoga šumskogospodarskoga područja. Površina istraživanoga područja iznosi 6170 ha. Izrađen je digitalni model reljefa razlučivosti 25 × 25 metara. Podaci o kamenitosti, stjenovitosti, nosivosti podloge i dubini tla pribavljeni su kao dio nacionalne inventure šuma od Javne šumarske službe Slovenije. Udaljenost od šumske ceste i smjer privlačenja dobiveni su iz mreže šumskih prometnica i digitalnoga modela reljefa. Gotovo polovica površine istraživanoga područja (48,9 %) ima nagib manji od 20 %, 30,1 % pripada u drugu kategoriju nagiba (20–40 %), dok su veći nagibi zastupljeni na manjim površinama. Kamenitost je utvrđivana u postotku površine prekrivene kamenom. Većina površine gospodarske jedinice ima kamenitost ispod 20 %, u razredu između 20 % i 40 % kamenitosti nalazi se 34,4 % površine, a u razredu preko 40 % kamenitosti 9,8 % ukupne površine gospodarske jedinice. Stjenovitost je razmatrana slično kao i kamenitost, kao postotni odnos ukupne površine prekrivene stijenama koje se ne mogu pomicati. Manja je od 20 % na 47,5 % površine, drugi razred (20–40 %) obuhvaća 43 %, a treći (<40 %) obuhvaća 9,4 % istraživane površine.

Ulazni kriterij za odabir načina privlačenja određen je na osnovi višekriterijske metodologije te primijenjen na istraživanom području. Potom su uspoređene referentna karta Javne šumarske službe Slovenije i karta modela. Naposljetku se pristupilo odabiru terenâ pogodnih za izvoženje drva i određivanju koji se ostali načini primarnoga transporta drva najozbiljnije suočavaju s tim oblikom transporta.

Ustanovljeno je da svojstva terena dopuštaju izvoženje drva na većoj površini nego što je to prikazano referentnom kartom. Najveće su promjene pri privlačenju drva traktorima, gdje je 64,7 % površine prvotno namijenjene privlačenju nizbrdo i 21,4 % površine namijenjene privlačenju uzbrdo oblikovanjem pripalo izvoženju drva. Uspoređujući područja koja su namijenjena iznošenju (šumske žičare) s ostalim načinima primarnoga transporta, utvrđeno je da oblikovani model pretpostavlja veće nagibe terena za rad šumskih žičara od one prikazane referentnom kartom. Privlačenje drva traktorom uz nagib najprihvatljivije je kod nagiba terena do 25 % i na kraćim udaljenostima privlačenja. Srednje udaljenosti privlačenja veće su kod funkcionalne klasifikacije terena (264 m) nego kod one dobivene iz referentne karte gdje iznose 226 metara.

Oblikovanjem je utvrđeno da se na istraživanom području izvoženje može primijeniti na većoj površini nego što je to prikazano referentnom kartom Javne šumarske službe Slovenije. Šume su istraživanoga područja većinom u privatnom vlasništvu, a to čini izvoženje drva teškim forvarderima malo vjerojatnim za primjenu. Treba očekivati da će se sječa i izradba odvijati ručno-strojno primjenom motorne pile lančanice, a izvoženje drva traktorskim ekipažama čiji su troškovi rada manji nego kod forvardera. Naveden je i osnovni razlog zbog čega su traktorske ekipaže uvedene u model.

Ključne riječi: vuča drva, izvoženje drva, sustavi privlačenja drva, GIS, karta privlačenja drva, modeliranje

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